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Supino

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(54) **COMPENSATING FOR VOICE COIL MOTOR AND MICROACTUATOR DISTURBANCE IN A HARD DRIVE**

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G11B 5/596	(2006.01)
G11B 5/48	(2006.01)
G11B 19/04	(2006.01)

(52) **U.S. Cl.**

CPC ***G11B 5/59694*** (2013.01); ***G11B 5/4873*** (2013.01); ***G11B 5/58*** (2013.01); ***G11B 5/59622*** (2013.01); ***G11B 19/042*** (2013.01)

(58) **Field of Classification Search**

CPC G11B 5/5582; G11B 5/59694; G11B 19/042; G11B 5/54; G11B 5/55; G11B 5/56; G11B 5/58; G11B 5/4873; G11B 5/59622

USPC 360/264.7, 266.4, 294.5, 97.19, 97.12, 360/75

See application file for complete search history.

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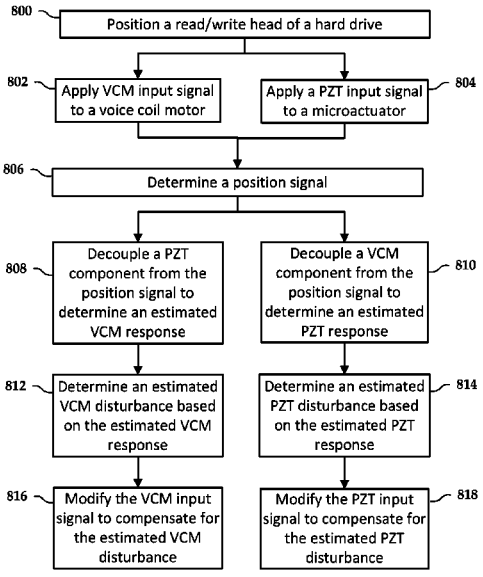
(57) **ABSTRACT**

In response to positioning a read/write head of a hard drive, a voice coil motor (VCM) input signal is applied to a voice coil motor and a microactuator (PZT) input signal is applied to a microactuator. A position signal is determined in response to positioning the read/write head. A PZT component is decoupled from the position signal to determine an estimated VCM response. The estimated VCM response used to determine an estimated VCM disturbance. A VCM component is decoupled from the position signal to determine an estimated PZT response. The estimated PZT response used to determine an estimated PZT disturbance. The VCM input signal and the PZT input signal are modified respectively to compensate for the estimated VCM disturbance and the estimated PZT disturbance.

20 Claims, 7 Drawing Sheets



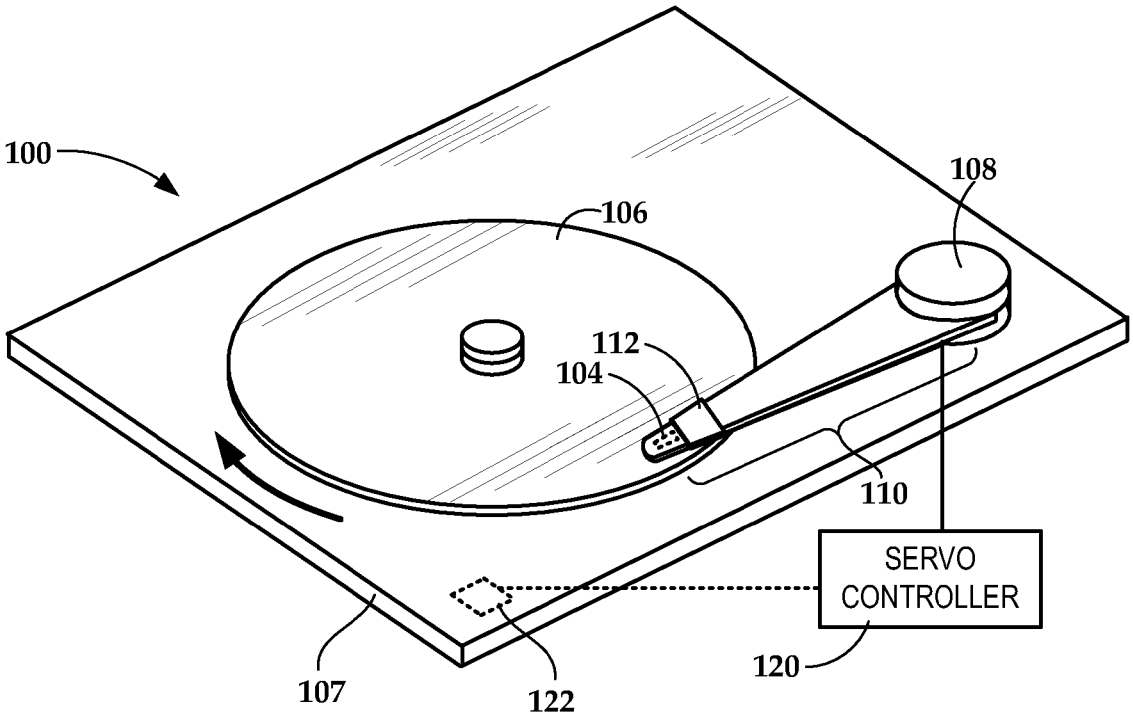


FIG. 1

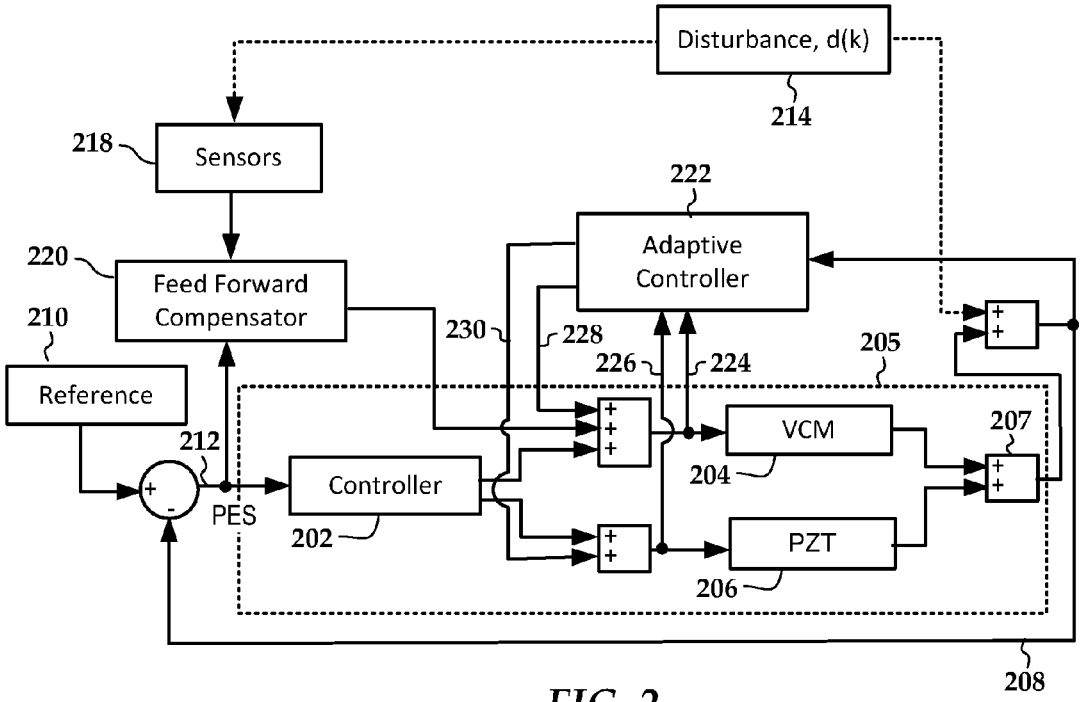

Disturbance, d(k)
214
218
Sensors
222
Adaptive Controller
220
Feed Forward Compensator
210
Reference
230
228
226
224
205
207
VCM
204
212
PES
Controller
202
PZT
206
208

FIG. 2

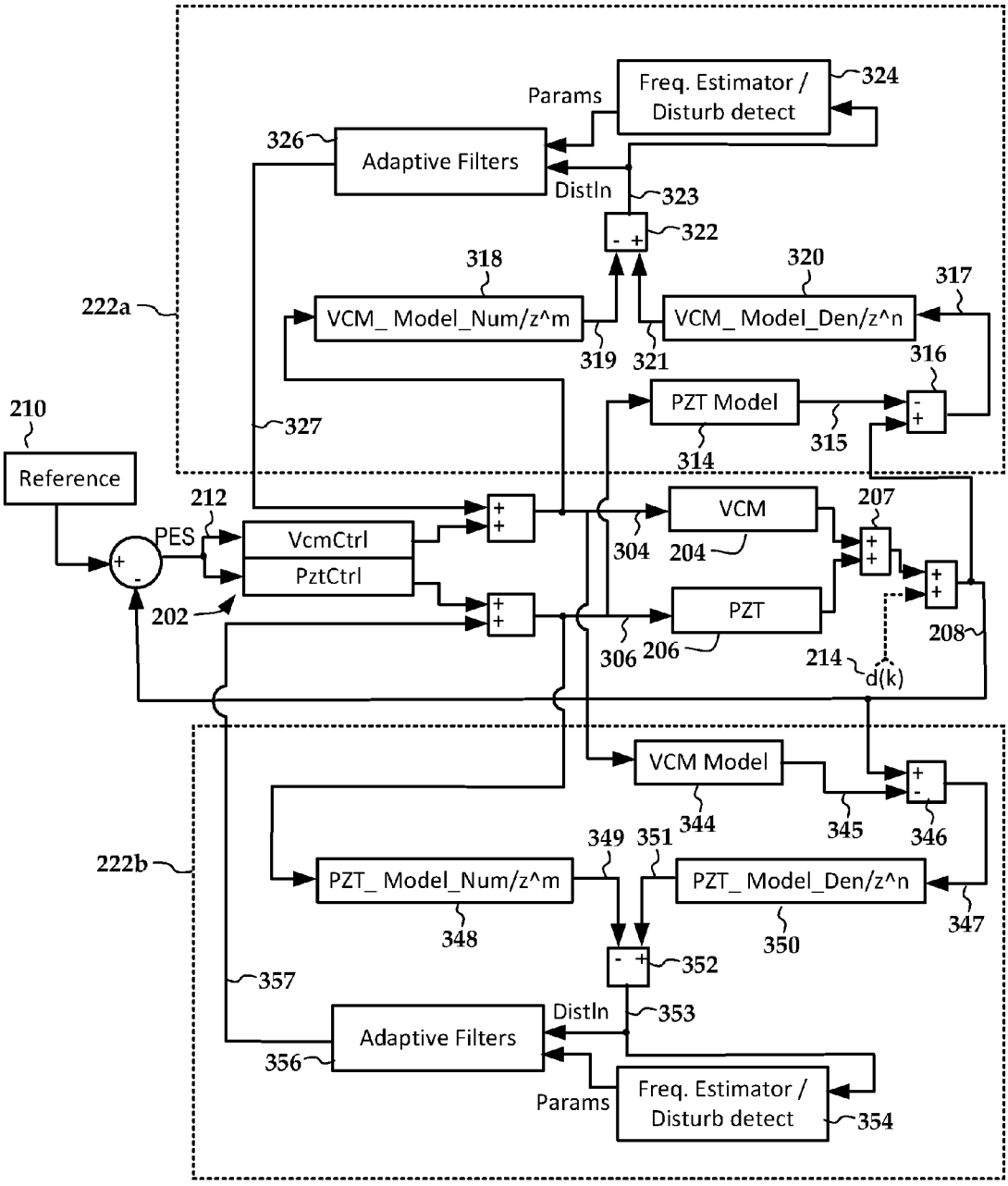

Freq. Estimator / Disturb detect
324
Params
326
Adaptive Filters
DistIn
323
322
318
320
317
222a
VCM_ Model_Num/z^m
VCM_ Model_Den/z^n
319
321
316
PZT Model
210
327
315
314
Reference
212
207
VCM
PES
VcmCtrl
PztCtrl
304
204
202
PZT
208
306
206
214
d(k)
VCM Model
344
345
346
349
351
222b
PZT_ Model_Num/z^m
PZT_ Model_Den/z^n
348
350
347
352
357
DistIn
353
Adaptive Filters
356
Params
Freq. Estimator / Disturb detect
354

FIG. 3

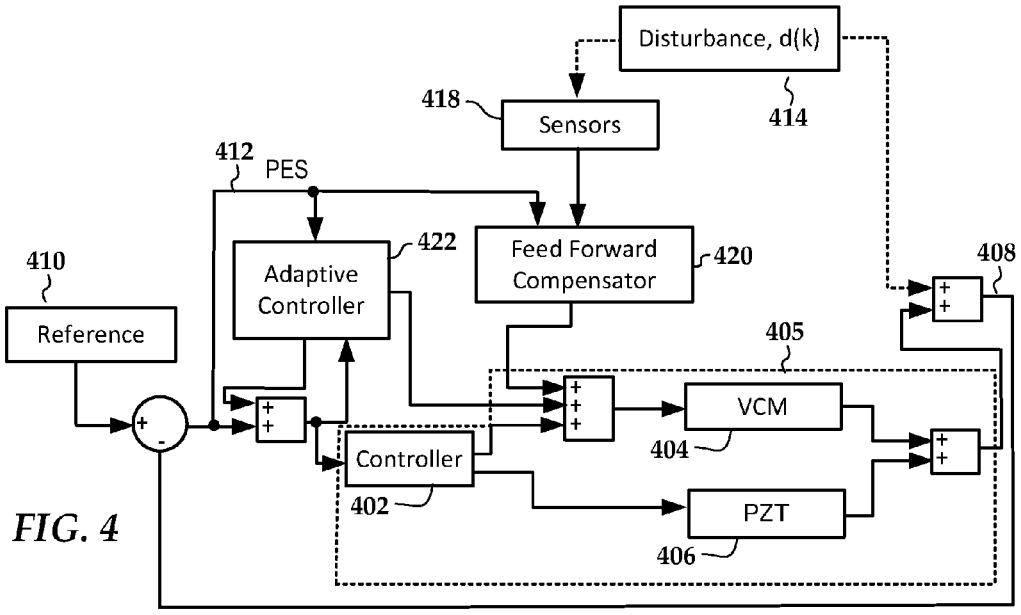

Disturbance, d(k)
414
418
Sensors
412
PES
410
Reference
Adaptive Controller
422
Feed Forward Compensator
420
408
405
VCM
404
Controller
402
PZT
406

FIG. 4

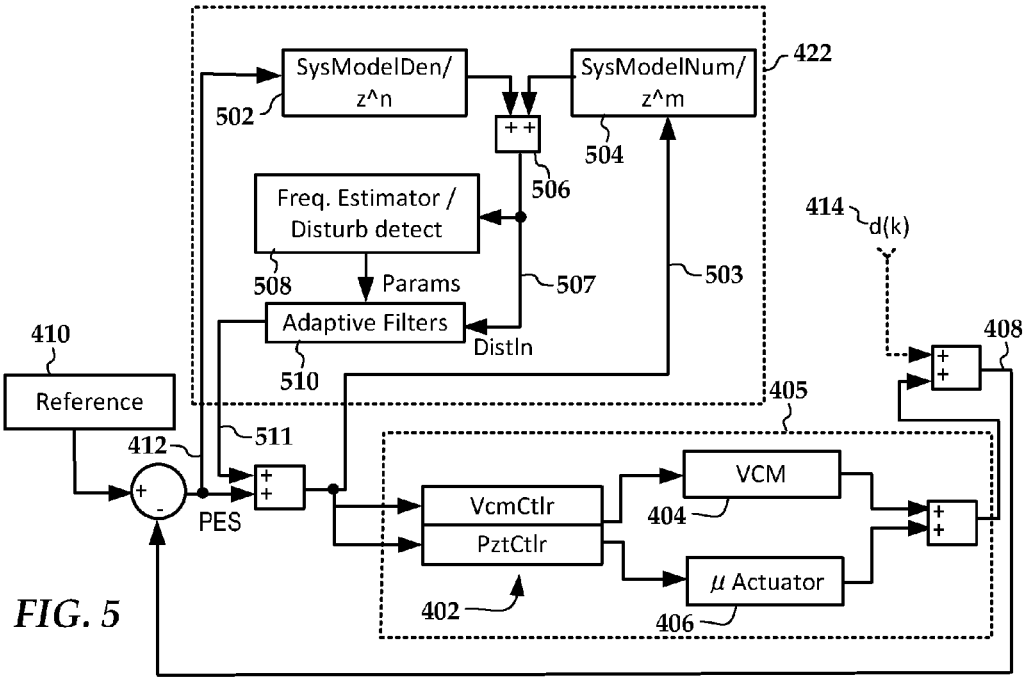

SysModelDen/ z^n
502
SysModelNum/ z^m
422
504
506
Freq. Estimator / Disturb detect
508
Params
507
503
414
d(k)
Adaptive Filters
DistIn
510
410
Reference
408
405
511
412
PES
VcmCtlr
PztCtlr
VCM
404
μ Actuator
402
406

FIG. 5

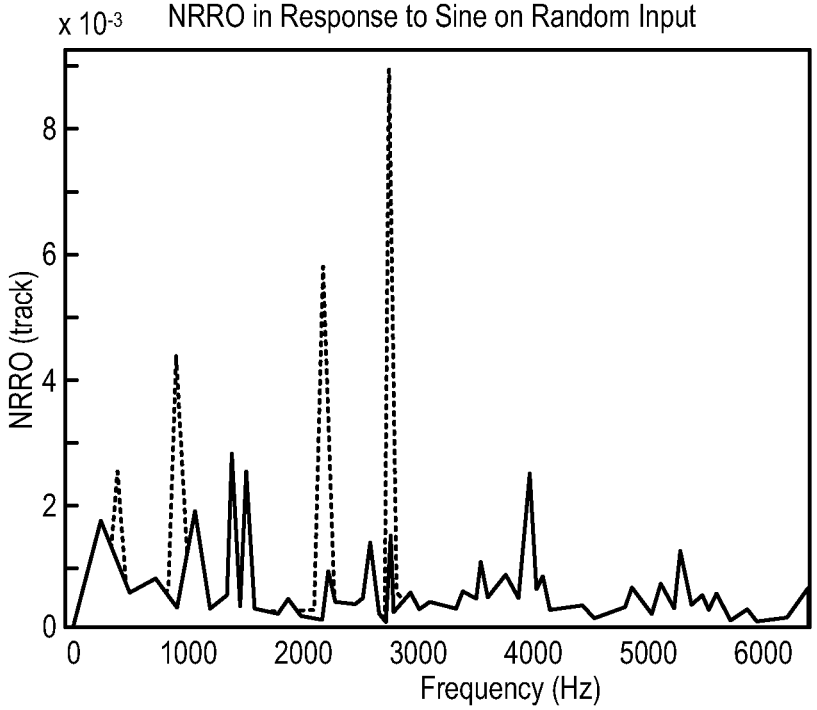

x 10-3
NRRO in Response to Sine on Random Input
NRRO (track)
8
6
4
2
0
0
1000
2000
3000
4000
5000
6000
Frequency (Hz)

FIG. 6

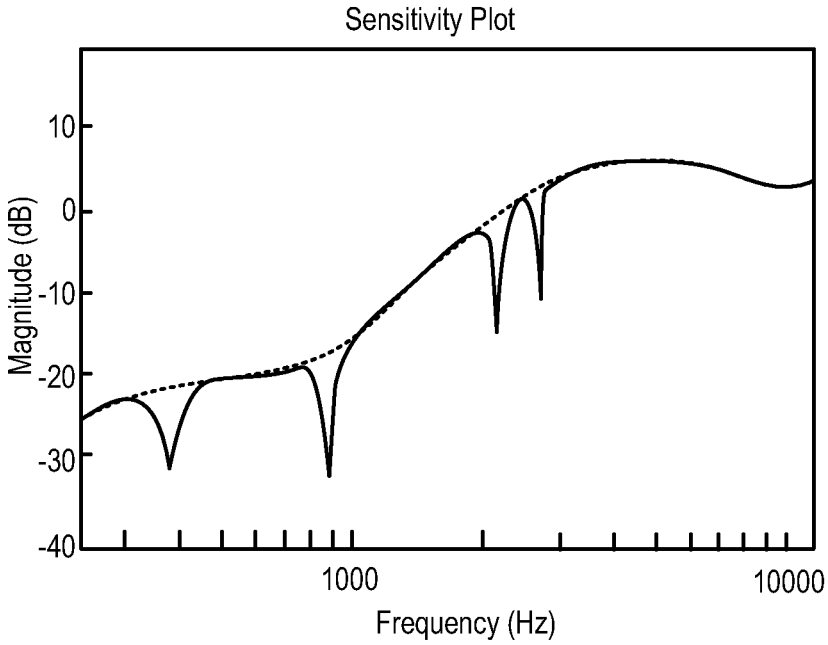

Sensitivity Plot
Magnitude (dB)
10
0
-10
-20
-30
-40
1000
10000
Frequency (Hz)

FIG. 7

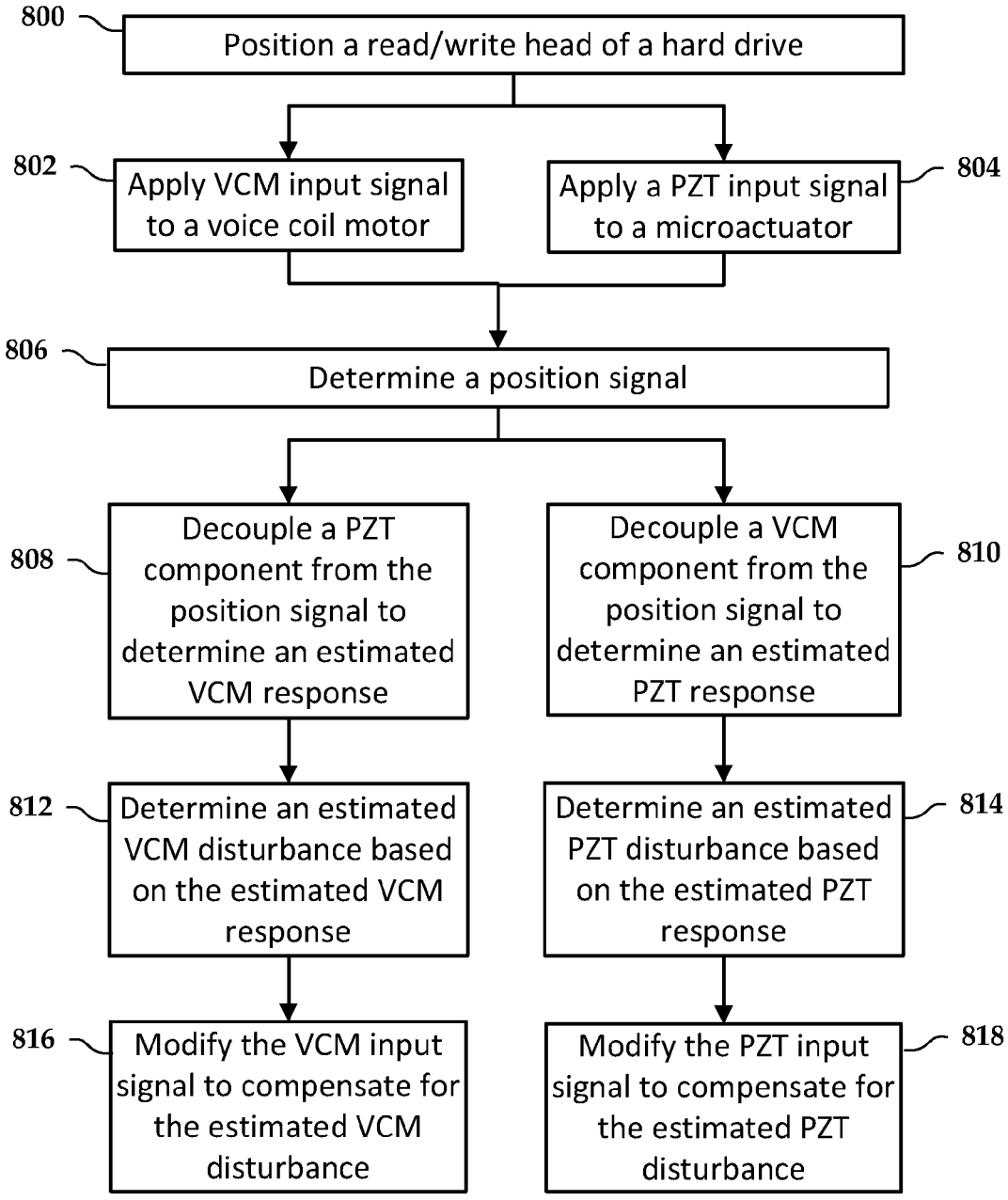

800
Position a read/write head of a hard drive
802
Apply VCM input signal to a voice coil motor
804
Apply a PZT input signal to a microactuator
806
Determine a position signal
808
Decouple a PZT component from the position signal to determine an estimated VCM response
810
Decouple a VCM component from the position signal to determine an estimated PZT response
812
Determine an estimated VCM disturbance based on the estimated VCM response
814
Determine an estimated PZT disturbance based on the estimated PZT response
816
Modify the VCM input signal to compensate for the estimated VCM disturbance
818
Modify the PZT input signal to compensate for the estimated PZT disturbance

FIG. 8

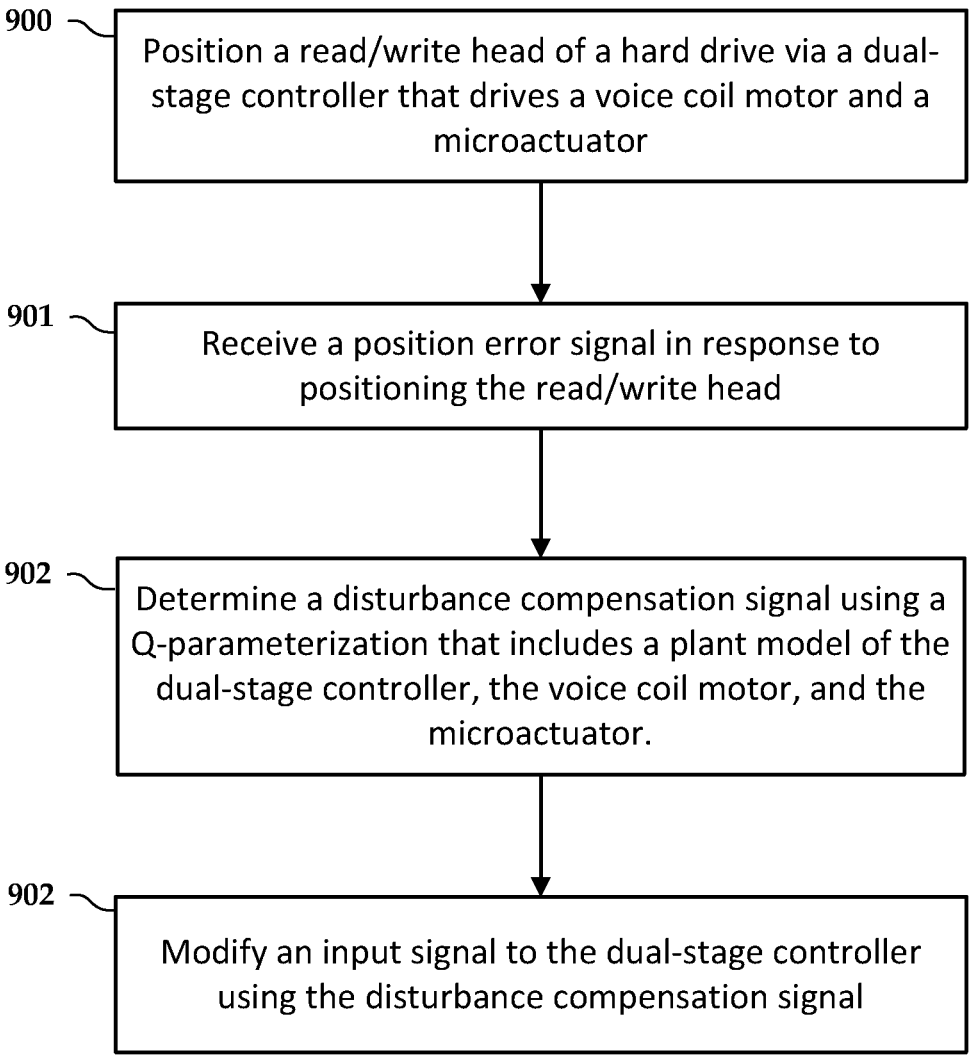

900
Position a read/write head of a hard drive via a dual-stage controller that drives a voice coil motor and a microactuator
901
Receive a position error signal in response to positioning the read/write head
902
Determine a disturbance compensation signal using a Q-parameterization that includes a plant model of the dual-stage controller, the voice coil motor, and the microactuator.
902
Modify an input signal to the dual-stage controller using the disturbance compensation signal

FIG. 9

COMPENSATING FOR VOICE COIL MOTOR AND MICROACTUATOR DISTURBANCE IN A HARD DRIVE

BACKGROUND

Some hard drives are designed with the assumption that significant movement of the drive may occur while the hard drive is operating. As such, the hard drives may include measures to compensate for shock and vibration that may occur during operation. However, even in a fixed installation, shock and vibration may be present present. For example, in a multi-drive configuration such as a disk array, the cooling fans as well as the drives themselves may generate vibrations that may be transmitted between hard drives through the structure in which they are mounted. This vibration can affect, among other things, tracking of the read/write head over the recording media. In other installations, speakers, force-feedback devices, and other vibration generating components may cause similar disturbances that affect a hard drive.

As areal density of hard drives increase, the track pitch may decrease significantly, leading to increased sensitivity to vibration that affects the read/write head. As a result, additional control mechanisms may be used to ensure read/write heads can reliably track over recording media with reduced track pitch.

SUMMARY

Various embodiments described herein are generally directed to methods, systems, and apparatuses that facilitate compensating for voice coil motor and microactuator disturbance in a hard drive. In one embodiment, a voice coil motor (VCM) input signal is applied to a voice coil motor and a microactuator (PZT) input signal is applied to a microactuator in response to positioning a read/write head of a hard drive. A position signal is determined in response to positioning the read/write head. A PZT component is decoupled from the position signal to determine an estimated VCM response. The estimated VCM response is used to determine an estimated VCM disturbance. A VCM component is decoupled from the position signal to determine an estimated PZT response. The estimated PZT response used to determine an estimated PZT disturbance. The VCM input signal and the PZT input signal are modified respectively to compensate for the estimated VCM disturbance and the estimated PZT disturbance.

In another embodiment, a servo controller is configured to receive a position error signal in response to positioning a read/write head of a hard drive via a dual-stage controller that drives a voice coil motor and a microactuator. A disturbance compensation signal is determined using a Q-parameterization that includes a plant model of the dual-stage controller, the voice coil motor, and the microactuator. An input signal to the dual-stage controller is modified using the disturbance compensation signal.

These and other features and aspects of various embodiments may be understood in view of the following detailed discussion and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The discussion below makes reference to the following figures, wherein the same reference number may be used to identify the similar/same component in multiple figures.

FIG. **1** is a perspective view of an apparatus according to an example embodiment;

FIG. **2** a block diagram of a dual-stage control system according to an example embodiment;

FIG. **3** is a block diagram showing an example configuration of the adaptive controller shown in FIG. **2**;

FIG. **4** a block diagram of a dual-stage control system according to another example embodiment;

FIG. **5** is a block diagram showing an example configuration of the adaptive controller shown in FIG. **4**;

FIGS. **6** and **7** are graphs showing vibration test results of an adaptive controller according to an example embodiment; and

FIGS. **8** and **9** are a flowcharts showing methods according to example embodiments.

DETAILED DESCRIPTION

The present disclosure relates generally to techniques for compensating for disturbances that affect a servo system that positions a read/write head of a hard disk drive. One technique for dealing with disturbance is known as feed-forward compensation. A feed-forward compensator generally operates by measuring vibration (e.g., via an accelerometer or piezoelectric sensor) and using the measurement to form a compensation signal. The compensation signal is combined with an actuator control signal to mitigate the effects of the disturbance.

While feed-forward compensation can be effective, it is not without its drawbacks. For example, the sensors may be susceptible to noise, which can cause erroneous compensation signals to be sent to the actuator. The actuator that moves the read/write head may be frequency limited, e.g., unable to reject disturbances above a certain frequency range. Due to the sensor placement of complexity of the structures, there may be only partial correlation between what the sensors detect and what is being experienced at the read/write head. Disturbance rejection may be inconsistent in the presence of variable narrow-band and wide-band disturbances.

The present disclosure describes architectures for sensorless disturbance estimation. The architectures provide disturbance compensation for hard disk drives without utilizing a vibration sensor input. The architecture may be used on devices without vibration sensors, may be used in a device where vibration sensors are included but not activated in some modes, and/or used to augment feed-forward control that includes vibration sensors. The proposed architectures are for dual-stage actuator servo systems. Such a system is shown in FIG. **1**, which is a perspective view that illustrates components of an apparatus **100** according to an example embodiment.

The apparatus **100** utilizes a dual-stage actuating system to position a slider **104** over a spinning magnetic media **106** (e.g., a hard disk). An electric motor (not shown) mounted on a basedeck **107** drives the media **106** to achieve the desired media velocity. The slider **104** includes a read/write head that records to and reads from the media **106**. The dual-stage actuating system includes a voice coil motor (VCM) **108** that drives an arm **110** with the slider **104** mounted at the end. The dual-stage actuating system also includes a microactuator **112** mounted in the arm **110** for fine tracking control of the slider **104**. The microactuator **112** may be referred to herein as a "PZT" in reference to a piezoelectric material used in some microactuators. However, such reference is not meant to limit the disclosure to PZT microactuators.

While only one arm **110** and slider **104** is shown, the apparatus **100** may include multiple such arms, one for each

surface of each disk **106** employed in the apparatus **100**. Each arm may contain a microactuator for individual fine tracking control, although all arms may be commonly driven by the VCM **108**. A servo controller **120** is capable of being electrically coupled to the microactuator **112** and VCM **108** to apply control signal. The servo controller **120** may also be coupled to read data back from the microactuator **112**, VCM **108**, and/or slider **104**, e.g., position signals, sensor data. The servo controller **120** includes at least one of a processor, memory, and specialized logic and analog circuitry (e.g., digital signal processing circuitry).

The illustrated microactuator **112** is shown located within a suspension of the arm **110**. In other configurations, the microactuator **112** may be positioned elsewhere, such as between the end of the arm **110** and the slider **104**. Generally, the microactuator **112** may be located anywhere in the apparatus **100** where it can assist a primary control component such as the VCM **108**. The functions of the microactuator **112** may include fine/fast tracking and seeking control, reduction of run-out and other functions that generally improve drive performance. While the illustrated dual-stage actuating system is shown as driving a pivoting arm **110**, concepts described below may be applicable to other types of drive systems, e.g., linear tracking arms.

One or more vibration sensors **122** can be located on the basedeck **107** and/or on any other hard drive component. The vibration sensor **122** measures rotational and/or linear vibration, which is used by the servo controller **120** for feed-forward compensation. Because the servo controller **120** implements a sensorless, dual-stage disturbance estimator, the vibration sensors **122** may be optional. The sensorless, dual-stage estimator provides a flexible solution which allows the most suitable actuator (VCM or microactuator) to adaptively compensate disturbances in different frequency ranges. Two architectures with different structures are described that achieve similar results.

In reference now to FIG. **2**, a control diagram illustrates dual-stage servo control according to a first example embodiment. Generally, a controller **202** provides signals to drive a VCM **204** and microactuator **206**. The VCM **204** and microactuator **206** together change a position of a read/write head, as indicated by block **207**. A reference input **210** is a command that drives the read/write head to a particular position. The actual position **208** is dual-stage servo response to the reference input **210** plus disturb **214**. The difference between the reference position **210** and actual position **208** is defined as position error signal (PES) **212**. The PES **212** is fed back to the controller **202**, and the system attempts to maintain a zero value of PES **202** during steady state operations, e.g., tracking.

Disturbance **214** represents exogenous forces affecting the read/write head. The disturbance **214** affects position of the read/write head, and the feedback path (position signal **208**) is used to offset the effects of disturbance. In addition, the disturbance may be detected by a vibration sensor **218** that is mounted on the device. A signal from the sensor **218** is processed by a feed-forward compensator **220**. In this example, the feed-forward compensator **220** sends a compensation signal to the VCM **204**.

While the same disturbance **214** is shown affecting both read/write head position **208** and sensor **218**, it will be understood that the actual manifestation of the disturbance may be significantly different. For example, the structural path between the sensors **218** and read/write head is complex and may exhibit a somewhat unpredictable response over a wide range of frequencies and operating conditions. Also, the feed-forward is only applied to the VCM **204** in this example, as the feed-forward compensator **220** may not be able to compensate for high frequency disturb in some cases.

To augment and/or replace the feed-forward compensator **220**, an adaptive controller **222** is used to provide sensorless, dual stage, disturbance rejection. The adaptive controller **222** receives respective input signals **224**, **226** applied to the VCM **204** and microactuator **206**, and provides respective compensation signals **228**, **230**. The adaptive controller **222** also uses the position signal **208**, as will be shown in greater detail in FIG. **3**.

In FIG. **3**, a block diagram illustrates additional details of the adaptive controller **222** shown in FIG. **2**. As seen in FIG. **3**, the adaptive controller **222** includes two sections, **222***a* and **222***b*. Controller section **222***a* provides disturbance compensation for the VCM **204** and section **222***b* provides disturbance compensation for the microactuator **206**. Each of these sections **222***a*, **222***b* computes a disturbance estimate for respective VCM **204** and microactuator **206**, creating an independent application of each disturbance rejection for each. These sections **222***a*, **222***b* may be configured as an "add-on feature" that determines/modifies the control effort to each actuator component.

Both controller sections utilize the position signal **208** in order to estimate respective response of the VCM **204** and microactuator **206**. For example, section **222***a* takes the input signal **306** applied to the microactuator **206** and applies this to a PZT model **314**. The resulting output **315** is an estimated PZT component of the position **208**, which is then subtracted from the position at block **316**. The resulting signal **317** is decoupled from the PZT components of position, and this signal **317** is transformed at block **320** via a denominator of a VCM transfer function (poles). The resulting output is a VCM plus disturb component **321** of the position signal.

The input signal **304** of the VCM **204** is transformed at block **318** via a numerator of the VCM transfer function (zeroes). This results in an estimate VCM component **319** of the of position signal. The estimate VCM component **319** is subtracted VCM plus disturb component **321**. Accordingly, the output of block **322** is an estimate **323** of VCM disturbance.

The VCM disturb estimate **323** may optionally be adaptively filtered, shown here being processed by a frequency estimator/disturbance detector block **324** (e.g., lattice filter, Goertzel filter, discrete Fourier transform) and an adaptive filter block **326**. The adaptive filter block **326** may use, but is not limited to, a joint process estimator (JPE), finite impulse response (FIR), bandpass filter (BPF), lowpass filter (LPF), etc. The output **327** of the controller section **222***a* is a disturbance estimate that can be used to cancel and/or reduce the disturbance, whether the disturbance is broadband and/or narrowband.

In section **222***b*, an input signal **304** applied to the VCM **204** is input to a VCM model **344**. The resulting output **345** is an estimated VCM component of the position **208**, which is then subtracted from the position **208** at block **346**. The resulting signal **347** is decoupled from the VCM components of position, and this signal **347** is transformed at block **350** via a denominator of a PZT transfer function (poles). The resulting output is a PZT plus disturb component **351** of the position signal.

The input signal **306** of the microactuator **206** is transformed at block **348** via a numerator of the PZT transfer function (zeroes). This results in an estimated PZT component **349** of the position signal. The estimated PZT component **349** is subtracted from the PZT plus disturb component **351**. Accordingly, the output of block **352** is an estimate **353** of PZT disturbance.

The microactuator disturb estimate **353** may optionally be adaptively filtered, shown here being processed by an optional frequency estimator/disturbance detector block **354** (e.g., lattice filter, Goertzel filter, discrete Fourier transform) and an adaptive filter block **356**. The adaptive filter block **356** may use, but is not limited to, a JPE, FIR, BPF, LPF, etc. The output **357** of the controller section **222***b* is a disturbance estimate that can be used to cancel/reduce a broadband and/or narrowband disturbance.

The total sensitivity function of the control systems shown in FIGS. **2** and **3** is a product of the baseline sensitivity and the sensitivity of the "add-on" feature, in this case the adaptive controller **222**. This is shown in Equation [1] below, where the baseline sensitivity is represented by the terms in the left hand set of square brackets, and the add-on feature is represented by the terms in the right square brackets. As the baseline system is stable and the adaptive controller **222** is stable, then the total system is stable. Equation [2] represents a difference equation for this system, where the Z values represent VCM and PZT delay, and the F values represent VCM and PZT adaptive filters.

$$S(z) = \left[\frac{1}{1 + Vcm * VcmCtlr + Pzt * PztCtlr}\right] * \left[\frac{(1 - F_{vcm})(1 - F_{pzt})}{(1 - F_{vcm}F_{pzt})}\right] \quad [1]$$

$$d(k) - Vcm(z)VcmCtlr(k) - Pzt(z)PztCtlr(k) = [1 - z^{-VCM_m}F_{vcm}(z) - z^{-PZT_m}F_{pzt}(z)]d(k) \quad [2]$$

In reference now to FIG. **4**, a block diagram illustrates a dual-stage, servo control architecture according to a second embodiment. This embodiment uses an add-on loop shaping technique known as Q-parameterization. A dual-stage controller **402** provides signals to drive a VCM **404** and microactuator **406**. Other elements, such as position/feedback signal **408**, reference input **410**, PES **412**, disturbance **414**, sensors **418**, and feed-forward compensator **420** are analogous to like-named elements described in relation to FIG. **2**.

An adaptive controller **422** configured as a dual-stage disturbance estimator is placed in front of the nominal dual stage controller **402**. The input to the nominal dual-stage controller **402** is augmented to reject the estimated disturbances. The adaptive controller **422** models the control system via plant model **405**, which includes controller **402**, VCM **404** and microactuator **406**. Using this model, a disturbance estimate is found using Q-parameterization.

Generally, Q-parameterization involves selecting a stabilizing feedback controller for a given plant as function of a single parameter, Q. For the illustrated control system, the stabilizing feedback controller can be expressed as shown in Equation [3], where Num(z) and Den(z) are respective numerator and denominator of the transfer function of the plant **205**, and X(z) and Y(z) are proper and stable and satisfy the vector function Num(z)X(z)+Den(z)Y(z)=1. The total sensitivity function of this control system is shown in Equation [4], where the baseline sensitivity is represented by the terms in the left hand set of square brackets, and the add-on feature is represented by the terms in the right square brackets. The terms P(z) and C(z) in Equation [4] are taken from the transfer function expressions shown in Equations [5a]-[5c].

$$C(z) = \frac{X(z) - Den(z)Q(z)}{Y(z) - Num(z)Q(z)} \quad [3]$$

-continued

$$S(z) = \left[\frac{1}{1 + P(z)C(z)}\right] * \left[1 - \frac{Num(z)}{Y(z)}Q(z)\right] \quad [4]$$

$$Sys(z) = \frac{Num(z)}{Den(z)} \quad [5a]$$

$$Sys(z) = Vcm(z)VcmCtlr(z) + Pzt(z)PztCtlr(z) \quad [5b]$$

$$Sys(z) = P(z)C(z) \quad [5c]$$

In FIG. **5**, a block diagram illustrates additional details of the adaptive controller **422** shown in FIG. **4**. The PES **412** is input to block **502**, which applies the denominator of the system transfer function (poles) and the disturbance-corrected PES **503** is input to block **504**, which applies the numerator of the system transfer function (poles). The output of these blocks **502**, **504** are summed at block **506**, and the resulting signal **507** are input to an optional frequency estimator/disturbance detector block **508** (e.g., lattice filter, Goertzel filter, discrete Fourier transform) and an adaptive filter block **510**. The adaptive filter block **510** may use, but is not limited to, a JPE, FIR, BPF, LPF, etc. The output **511** of the adaptive controller **422** is a disturbance estimate that can be used to cancel/reduce a broadband and/or narrowband disturbance.

In FIGS. **6** and **7**, graphs illustrate results of tests conducted using an adaptive controller as described above. Results were similar for both types of adaptive controllers shown in FIGS. **2** and **4**. The graph in FIG. **6** represents an example of non-repeatable runout (NRRO) in response to a sine-on-random rotational vibration profile applied to a hard drive on a shake table. In this example, four sine tones with center frequencies ranging from 380 Hz to 2.7 kHz simulate external vibration inputs that might be generated, for example, by other hard drives, cooling fans, cooling airflow, etc. The dashed curve in FIG. **6** represents the NRRO response with the adaptive controller deactivated, and the solid curve represents NRRO response with the adaptive controller activated. The four large peaks in the dashed curve correspond to the center frequencies of the sinusoidal vibration inputs, the effects of which are mitigated by the adaptive controller as shown by the solid curve. In FIG. **7**, the dashed line represents measured sensitivity of the servo system without the adaptive controller, and the solid line illustrates the sensitivity with the adaptive controller activated. The dips in sensitivity are centered around the center frequencies of the sine tones in FIG. **6**, and help mitigate the disturb effects of the externally applied vibration.

Due to the dynamic environment in which a hard drive operate, a profile such as seen in FIG. **6** may be transient, and other profiles may be observed over time due to, among other things, changes in equipment operating speed, changes in ambient conditions, workload on the hard drive, etc. As such, the adaptive nature of the disturb compensation allows shifting the location and magnitude of sensitivity notches as shown in FIG. **7** to adjust for current conditions of use.

In FIG. **8**, a flowchart illustrates a method according to an example embodiment. The method involves, in response to positioning **800** a read/write head of a hard drive, applying **802** a VCM input signal to a voice coil motor and applying **804** a PZT input signal to a microactuator. A position signal is determined **806** in response to positioning the read/write head.

A PZT component is decoupled **808** from the position signal to determine an estimated VCM response. The estimated VCM response is used to determine **812** an estimated VCM disturbance. The VCM input signal is modified **816** to

compensate for the estimated VCM disturbance. A VCM component is decoupled **810** from the position signal to determine an estimated PZT response. The estimated PZT response used to determine **814** an estimated PZT disturbance. The PZT input signal is modified **818** to compensate for the estimated PZT disturbance.

In FIG. **9**, a flowchart illustrated a method according to another embodiment. The method involves positioning **900** a read/write head of a hard drive via a dual-stage controller that drives a voice coil motor and a microactuator. A position error signal is received **901** in response to the positioning of the read/write head. A disturbance compensation signal is determined **902** using a Q-parameterization that comprises a plant model of the dual-stage controller, the voice coil motor, and the microactuator. An input signal to the dual-stage controller is modified **903** using the disturbance compensation signal.

Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

The various embodiments described above may be implemented using circuitry, firmware, and/or software modules that interact to provide particular results. One of skill in the arts can readily implement such described functionality, either at a modular level or as a whole, using knowledge generally known in the art. For example, the flowcharts and control diagrams illustrated herein may be used to create computer-readable instructions/code for execution by a processor. Such instructions may be stored on a non-transitory computer-readable medium and transferred to the processor for execution as is known in the art. The structures and procedures shown above are only a representative example of embodiments that can be used to provide the functions described hereinabove.

The foregoing description of the example embodiments has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. Any or all features of the disclosed embodiments can be applied individually or in any combination are not meant to be limiting, but purely illustrative. It is intended that the scope of the invention be limited not with this detailed description, but rather determined by the claims appended hereto.

What is claimed is:

1. A method comprising:

applying a voice coil motor (VCM) input signal to a voice coil motor and a microactuator (PZT) input signal to a microactuator in response to positioning a read/write head of a hard drive;

determining a position signal in response to positioning the read/write head;

decoupling a PZT component from the position signal to determine an estimated VCM response, the estimated VCM response used to determine an estimated VCM disturbance;

decoupling a VCM component from the position signal to determine an estimated PZT response, the estimated PZT response used to determine an estimated PZT disturbance; and

modifying the VCM input signal and the PZT input signal respectively to compensate for the estimated VCM disturbance and the estimated PZT disturbance.

2. The method of claim **1**, further comprising adaptively filtering the estimated VCM disturbance and the estimated PZT disturbance.

3. The method of claim **2**, wherein adaptively filtering comprises using one of a lattice filter, Goertzel filter, and discrete Fourier transform to estimate disturb frequencies.

4. The method of claim **2**, wherein adaptively filtering comprises using at least one of joint process estimator and finite impulse response filter.

5. The method of claim **1**, further comprising modifying the VCM input signal further via a feed-forward compensator to compensate for measured VCM disturbance.

6. An apparatus comprising:

a servo controller configured to:

apply a voice coil motor (VCM) input signal to a VCM and a microactuator (PZT) input signal to a PZT to position a read/write head of a hard drive;

determine a position signal in response to positioning the read/write head;

decouple a PZT component from the position signal to determine an estimated VCM response, the estimated VCM response used to determine an estimated VCM disturbance;

decouple a VCM component from the position signal to determine an estimated PZT response, the estimated PZT response used to determine and an estimated PZT disturbance; and

modify the VCM input signal and the PZT input signal respectively to compensate for the estimated VCM disturbance and the estimated PZT disturbance.

7. The apparatus of claim **6**, wherein the servo controller is further configured to adaptively filter the estimated VCM disturbance and the estimated PZT disturbance.

8. The apparatus of claim **7**, wherein adaptively filtering comprises using one of a lattice filter, Goertzel filter, and discrete Fourier transform to estimate disturb frequencies.

9. The apparatus of claim **7**, wherein adaptively filtering comprises using at least one of joint process estimator and finite impulse response filter.

10. The apparatus of claim **6**, wherein the servo controller is further configured to:

transform the VCM input signal via a VCM model to obtain an estimated VCM component of the position signal;

transform a difference between the estimated VCM component and the position signal via a denominator of a PZT transform function to obtain a PZT plus disturb component of the position signal;

transform the PZT input signal via a numerator of the PZT transform function to obtain an estimated PZT component of the position signal; and

subtract the estimated PZT component from the PZT plus disturb component to obtain the estimated PZT disturbance.

11. The apparatus of claim **10**, wherein the servo control processor is further configured to adaptively filter the estimated PZT disturbance.

12. The apparatus of claim **11**, wherein adaptively filtering comprises using one of a lattice filter, Goertzel filter, and discrete Fourier transform to estimate disturb frequencies.

13. The apparatus of claim **6**, wherein the servo controller is further configured to:

transform the PZT input signal via a PZT model to obtain an estimated PZT component of the position signal;

transform a difference between the estimated PZT component and the position signal via a denominator of a VCM transform function to obtain a VCM plus disturb component of the position signal;

transform the VCM input signal via a numerator of the VCM transform function to obtain an estimated VCM component of the position signal; and

subtract the estimated VCM component from the VCM plus disturb component to obtain the estimated VCM disturbance.

14. The apparatus of claim **13**, wherein the servo controller is further configured to adaptively filter the estimated VCM disturbance.

15. The apparatus of claim **14**, wherein adaptively filtering comprises using one of a lattice filter, Goertzel filter, and discrete Fourier transform to estimate disturb frequencies.

16. An apparatus comprising:

a servo controller configured to:

receive a position error signal in response to positioning a read/write head of a hard drive via a dual-stage controller that drives a voice coil motor and a microactuator;

determine a disturbance compensation signal using a Q-parameterization that comprises a plant model of the dual-stage controller, the voice coil motor, and the microactuator, the Q-parameterization comprising selecting a stabilizing feedback controller for the plant model as function of a single parameter;

modify an input signal to the dual-stage controller using the disturbance compensation signal.

17. The apparatus of claim **16**, wherein the Q-parameterization determines the disturbance compensation signal based on the input signal and the modified input signal.

18. The apparatus of claim **16**, wherein the servo control processor is further configured to adaptively filter the disturbance compensation signal.

19. The apparatus of claim **18**, wherein adaptively filtering comprises using one of a lattice filter, Goertzel filter, and discrete Fourier transform to estimate disturb frequencies.

20. The apparatus of claim **18**, wherein adaptively filtering comprises using at least one of joint process estimator and finite impulse response filter.

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